Controlled-source magnetotellurics for groundwater

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SUMMARY

An electromagnetic method using tensor AMT and tensor CSAMT measurements has been developed for high resolution conductivity mapping of the shallow subsurface. Portable vertical loop transmitters are used to supplement the natural source fields at frequencies above 1 kHz, enabling continuous frequency coverage from 1 Hz to 100 kHz. Survey data collected for a saltwater invasion study in the Salinas Valley area in California has identified hydrogeologic features that match well log information.

INTRODUCTION

The search for groundwater, and the efforts to map groundwater quality, have tended to relay on logical model concepts and corresponding one dimensional interpretations of EM data. The general hydrogeological model is complex and usually the lateral variations such as channels are of interest. Lateral definitions of inhomogeneities are of paramount importance and methods which relay on an integration or smoothing of the response to emphasize the layered aspects of the ground may be inappropriate. The very inhomegeneities of the near surface, which have been "geologic noise" for mineral and petroleum surveys, may be the desired targets in hydrogeology studies. The maximum resolution for such lateral conductivity variations is provided in measurements of the electric field.

The electric field is discontinuous across a vertical contrast between media of different conductivities, while the magnetic field varies smoothly. Configurations such as those used in the in-loop transient method are designed to minimize or to avoid such near surface problems by using the late time response to interpret deeper average values of the conductivity. The near surface variations in electric field have been considered a problem for surveys for deeper targets because it is not practical to sample the electric field properly. For shallow studies, the logistics of continuous sampling are practical and continuous linear or areal mapping of the surface impedance becomes highly advantageous and cost effective. Furthermore, there are effective 2-D and 3-D inversion schemes for MT data (Smith and Booker, 1991, deGroot-Hedlin and Constable, 1990), but such algorithms are not available for controlled source or transient em methods in generally inhomogeneous media.

A NEW CONTROLLED SOURCE MT METHOD

We have developed a hybrid natural field-controlled source system for making continuous impedance measurements along profiles or on grids in the 1 Hz to 100 kHz band. Natural fields are employed to 500 Hz and a controlled source is used for frequencies above 1000 Hz. The approach is similar to that used in controlled source audiomagnetotellurics (CSAMT) with the following notable differences:

a) the complete tensor impedance is measured using orthogonal electric and magnetic field sensors (Figure 1);
b) the controlled source is only used for frequencies above 1000 Hz. This enables a dramatic reduction in the required transmitter moment since to be in the far field for such frequencies requires much smaller separations between the source-receiver, and the transmitted field roughly falls off with the cube of separation distance.
c) for frequencies above 1000 Hz, the vertical loops become the ideal source (Figure 1). Orthogonal vertical loops provide both a rotating field (for tensor impedance determination), simple deployment with no ground contact, and adequate moment with simple portable power supplies (< 1 kwatt);
d) the practical difficulties of measuring along profiles or on grids are manageable when electrode spacing is 5 to 30 meters rather than 50 to 200 meters, as used with CSAMT for deeper investigations.

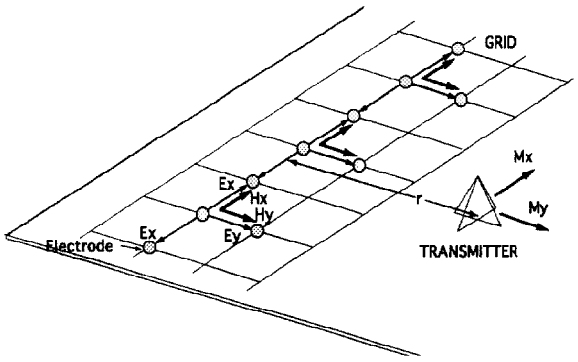

FIG. 1. Schematic diagram of survey configuration.

MODEL CALCULATION AND FIELD DATA

A typical groundwater problem is illustrated in Figure 2. Two gravel-sand aquifers in the form of channels are buried in a sequence of salt-clay formations. One of the aquifers is resistive (fresh water) and the other has been invaded by sea water and is conductive. The TE magnetotelluric response and the corresponding section composed of 1-D Bostick inversions (Torres-Verdin and Bostick, 1992) is shown in Figure 2. These 1-D inversions reveal the general features of the subsurface, but are principally useful for providing initial models for the full 2-D inversions. We have found that in many groundwater studies, the 1-D inversions, especially those applied after spatial filtering, provide good images of the

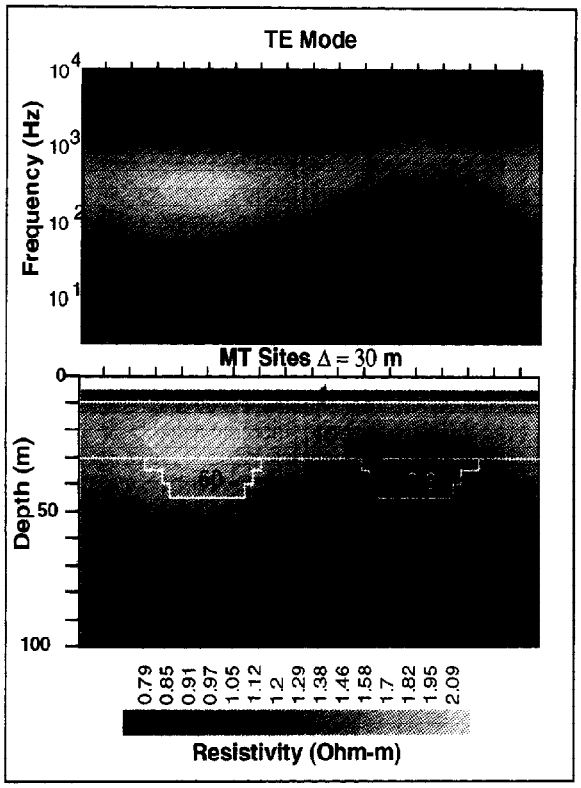

FIG. 2. Resitivity pseudosection for simulated two buried aquifer channels.

subsurface and are all that is needed for hydrogeological interpretation. An example from a sea water invasion study in the Salinas Valley, CA, is shown in Figure 3. Here the survey frequencies were 10 Hz to 10 kHz and the objective was to locate fresh water aquifers (resistive channels) below a shallow aquifer which had been invaded (conductive features in the upper 50 m of the section). Figure 3 shows the section derived from 1-D Bostick inversions of standard EMAP processing of the TM mode and the electric logs of two wells in the section. A full inversion of the data yields a more accurate section but, for this study the approximate method was satisfactory. This and other model simulations and field data show the distinct advantages of continuous profiling with electric and magnetic fields.

REFERENCES

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Torres-Verdin, and C., Bostick, F.X. Jr., 1992, Principles of spatial surface electric field filtering in magnetotellurics: Electromagnetic array profiling (EMAP): Geophysics, 57, 603-622.

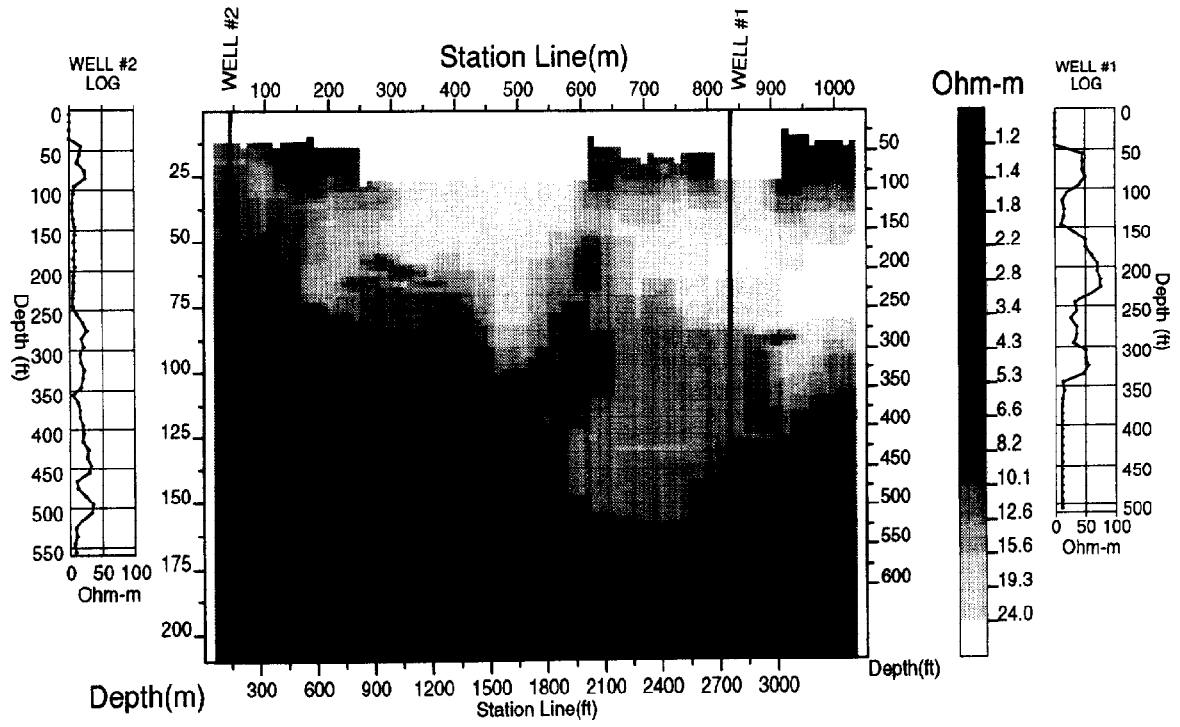
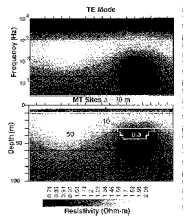
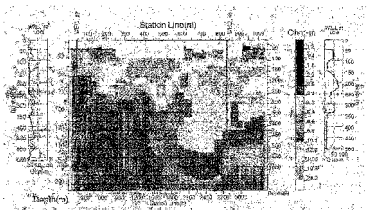


FIG. 3. 1-D inverted section of a spatially filtered MT profile line taken to assess the extent of sea water invasion in an agricultural area in the Salinas Valley, California.


TE Mode
Frequency (Hz)
MT Sites, Δ = 10 m
Depth (m)
50
10
1.0
Resistivity (Ohm-m)


Station Line(nt)
Depth(m)